Effect of Weathering Conditions on Wood Surface Roughness: Optimal Parameters Determined *via* Taguchi Analysis

Erol İmren *

Wood when exposed to accelerated weathering conditions is deteriorated as a result of factors such as UV rays, temperature, and relative humidity changes. The surface roughness of wood also undergoes substantial changes. In this study, the effect of accelerated weathering conditions on surface roughness changes on Scots pine (*Pinus sylvestris* L.) and poplar (*Populus* x *euroamericana*) wood surfaces were investigated using the Taguchi method. The parameters most affecting the surface roughness were radial direction, 0.5 W/m^2 UV, 4 h conditioning time, and 45 min water for Scots pine, and tangential direction, 0.5 W/m^2 UV, 2 h conditioning, and 15 min water for poplar wood. The variables that most affected the surface roughness were conditioning with 38% in Scots pine wood and wavelength with 31% in poplar wood.

DOI: 10.15376/biores.17.4.6668-6678

Keywords: Accelerated weathering; Surface roughness; Optimization; Taguchi method

*Contact information: Department of Forest Industrial Engineering, Faculty of Forestry, Bartin University, Bartin, Turkey; *Corresponding author: eimren@bartin.edu.tr*

INTRODUCTION

In outdoor conditions, color changes, cracks, and surface roughness occur on the wood surface with the effect of sunlight (UV), humidity (rain, snow), mechanical forces, and temperature. In addition, changes are observed in the chemical and physical properties of the material (Feist and Hon 1984; Williams 2005; Kilic and Hafizoglu 2007). The degradation mechanism is affected by sunlight, wood type, temperature, humidity, atmospheric pollution, oxygen, hot/cold temperature, wind erosion, chemicals, and biological factors (Feist and Hon 1984; Williams 2005; Kamperidou and Barboutis 2021). Among these factors, the effect of UV and water is thought to be important during wood material use in outdoor conditions (Feist and Hon 1984; Zhang *et al.* 2009). As a result of UV rays, degradation in wood occurs because of chemical changes such as an increase in carboxyl and acidity ratio and a decrease in methoxyl and lignin contents. As a result, the soluble lignin degradation products on wood surfaces exposed to outdoor conditions are washed by rainwater, leaving behind cellulose-rich surfaces (Temiz *et al.* 2005 *et al.*; Can 2018). Color changes, openings, and cracks occur on wood surfaces with the effect of sunlight and water. The strength of cell wall bonds close to the surface is lost and degradation occurs as a result.

In general, many variables and parameters affect the wood material in the external environment. Given the complex and detailed nature of real life, some of these variables are sufficient to estimate the main effects. In contrast, using variables excessively prevents the creation of an effective and efficient model. For this reason, the model should represent the population most effectively in terms of both time and cost factors (Cabuk *et al.* 2014).

Experimental design methods, in addition to their statistical significance, are complementary and supportive methods that can be used in all research and development applications, increasing quality, minimizing costs, and thus reinforcing the reliability of the outputs obtained. To this end, Dr. Taguchi has brought a solution that will increase efficiency in the realization of experiments and evaluation of applications (Ross 1989). In addition to being an experimental design method, the Taguchi method is a useful technique for high quality system design by reducing the number of experiments (Taguchi *et al.* 1989).

For the analysis of the test outputs obtained in the Taguchi experimental design method, the loss function is converted into a statistical performance measure known as the signal-to-noise ratio (S/N ratio). Thus, the deviation between the data is calculated (Koksoy and Muluk 2004; Kivak 2014; Kurt and Can 2021). According to its characteristic feature, this ratio is calculated with objective functions (Masmiati and Sarhan 2015) as follows:

$$\text{Nominal best } \frac{S}{N} = 10\log\left(\frac{\bar{y}}{S_y^2}\right) \quad (1)$$

$$\text{Highest best } \frac{S}{N} = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right) \quad (2)$$

$$\text{Lowest best } \frac{S}{N} = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \quad (3)$$

where $\bar{y}$ is the mean of the observed data, S_y^2 is the variance of y, n is the number of experiments, and y is the observed data.

Application stages according to Taguchi experimental design method involve the following: (1) Selection of factors and evaluation of interactions between them; (2) Determining the levels of factors; (3) Choosing the right balanced design; (4) Matching the factors and/or interactions between them with columns in a balanced experiment order; (5) Execution of the experiments as planned in the previous steps; and (6) Analysis of the results and conducting confirmation experiments (Yang and Tarng 1998). Through estimating the effect of the factors considered in the experiment on the quality value, the quality value that can be obtained as a result of the optimum experimental parameters can be found. While determining the optimum levels of the factors, R_a (mean surface roughness) values should be the smallest to increase the efficiency of the process. Therefore, the least-best objective function of the performance characteristic is used to calculate the S/N ratios.

Wood is one of the most abundant materials in nature, and its use and production are increasing day by day (Kurt and Imren 2021). Wood is a renewable material with low density, low thermal conductivity, high mechanical strength, easy workability, and good aesthetic appearance. When wood is exposed to natural conditions without any protective treatment, it deteriorates under ultraviolet (UV) light (De la Caba *et al.* 2007). Therefore, leaching, hydrolysis and swelling of water, discoloration and decay by microorganisms can occur. Thus, chemical changes of wood, color changes, microscopic changes, physical changes and changes caused by biological factors change as a time-dependent effect (Kurt and Can 2021).

It is essential to understand the processing properties, surface characteristics and anatomical structure of wood in the best way in order to enable the use of quality products and to increase its share in national and international markets. Considering the surface quality, which is the most important factor determining the quality in the woodworking sector, it is a desired feature for wood and wood-like products to have a quality surface, especially after processing, both during and after production (Aras and Sofuoğlu 2021). Characteristics of wood material such as color, pattern, and texture determine the quality of the products obtained, and these properties make it different from other materials. One of the important characteristics of wood is its ease of processing and manufacture. However, tree species show quite significant differences in operations with various tools or machines (Kaygin *et al.* 2014). For this reason, it is necessary to determine the treated wood surface property, which is a first-degree indicator for various uses, with some systematic methods. The smooth surface of the wooden material increases the preferability of the quality surface product. In addition, it is very important to obtain a good surface quality during the processing of wood material and to achieve it with the least cost. In order to obtain smooth surfaces in wood material, a suitable combination of processing conditions must be applied.

This study used the Taguchi method to determine the factors affecting the surface roughness change of wood material after accelerated weathering. In addition, the effect of cutting direction (radially, tangentially) and tree species on the roughness change was investigated.

EXPERIMENTAL

Materials

The Kartal Ahsap Company (Bartin, Turkey) provided Scots pine (*Pinus sylvestris* L., oven-dry density of 0.49 g/cm^3) and poplar (*Populus* x *euroamericana*, oven-dry density of 0.28 g/cm^3) timbers. The wood was chopped into specimens of dimensions 5 cm × 7.5 cm × 15 cm (diameter × width × length). Wood samples were taken from a single lawn. The timber was dried under outdoor conditions for six months and then cut to the sample size. Tangential and radial surfaces were carved into the specimens. The test specimens were free of knots and had no apparent signs of mold or fungal contamination. The wood specimens were placed in the conditioning room at 65% relative humidity (RH) and 22 °C prior to weathering to achieve a constant weight following the ISO 554 (2016) method.

Methods

Accelerated weathering test (QUV)

The ASTM standard G154-16 (2016) was used to conduct the accelerated weathering test. Different parameters were used to determine the impact of various weathering elements on the overall color change. A 340 nm lamp (340 nm fluorescent UV lamps) was employed in the UV procedure, and the average temperature in the chamber was set to 50 °C. The accelerated weathering was applied to four replicate specimens of each variety. The UV treatment lasted a total of 24 h. Water (for 15, 30, and 45 min) and conditioning (for 2, 4, and 6 h) treatments were performed after every 2 h of UV treatment.

Water spray was used for 45 min following a 2 h 0.5 W/m^2 UV application. The sample was conditioned for 6 h at 50 °C in the accelerated weathering cycle after receiving the water spray treatment. The test group's accelerated weathering was accomplished after repeating the accelerated weathering test 24 times.

Effect of weathering on wood surface roughness

The Mitutoyo Surftest SJ-301 device (Mitutoyo Corporation, Kanagawa, Japan) was used for surface roughness measurements. The mean surface roughness (R_a) and maximum height (R_z) values of the test samples were determined and evaluated. According to the ISO 25178-2:(2012) standard, separate measurements were made on the tangential and radial surfaces of Scots pine and poplar wood samples. In the measurements, the limit wavelength used was 8 mm, the speed was 0.5 mm/s, and the scanning length was 12 mm. Ten measurements were made to evaluate the surface roughness of each group.

Taguchi experiment design

To determine the effect of weathering on wood surface roughness (R_a), UV-irradiance (W/m^2), conditioning (h), and water (min) were used. Parameters and their respective levels are given in Table 1.

Table 1. Roughness Variation Parameters and Levels

Codes	Parameters	Levels		
		1	**2**	**3**
A	Direction	Radial	Tangential	-
B	UV-Irradiance (W/m^2)	0.5	0.75	1.00
C	Conditioning (h)	2	4	6
D	Water (min)	15	30	45

An orthogonal array was used to determine the optimum conditions. In Table 2, the experimental conditions, the *Ra* values measured before and after weathering, and the change in the values are given. Optimization process was performed on percentages of change.

Statistical analysis

Statistical analysis was performed using Minitab 18 software (Minitab LLC, State College, PA, USA).

Table 2. R_a Values Before (BW) and After (AW) Weathering, Rate of Change, and Orthogonal Array of Taguchi $L_{18}(2^1\ x\ 3^3)$

Experiment No.	Scots Pine							Poplar						
	A	**B**	**C**	**D**	**R_a BW**	**R_a AW**	**Change (%)**	**A**	**B**	**C**	**D**	**R_a BW**	**R_a AW**	**Change (%)**
1	1	1	1	1	9.4	11.63	23.71	1	1	1	1	8.46	8.97	6.01
2	1	1	2	2	5.33	6.11	14.60	1	1	2	2	6.15	12.46	102.55
3	1	1	3	3	6.13	7.48	22.10	1	1	3	3	7.95	8.45	6.28
4	1	2	1	1	6.43	9.63	49.80	1	2	1	1	5.92	12.44	110.08
5	1	2	2	2	3.73	4.47	19.97	1	2	2	2	8.3	15.24	83.6

Experiment No.	Scots Pine							Poplar						
	A	B	C	D	R_a BW	R_a AW	Change (%)	A	B	C	D	R_a BW	R_a AW	Change (%)
6	1	2	3	3	3.61	7.48	107.29	1	2	3	3	12.57	20.36	61.94
7	1	3	1	2	4.21	7.59	80.38	1	3	1	2	9.73	19.39	99.26
8	1	3	2	3	8.26	8.43	2.010	1	3	2	3	7.93	11.31	42.6
9	1	3	3	1	6.18	12.30	99.08	1	3	3	1	8.68	14.07	62.11
10	2	1	1	3	7.64	8.10	6.030	2	1	1	3	12.76	17.20	34.81
11	2	1	2	1	4.64	5.23	12.63	2	1	2	1	12.68	12.83	1.16
12	2	1	3	2	4.66	8.47	81.85	2	1	3	2	6.84	11.02	61.17
13	2	2	1	2	4.35	6.47	48.71	2	2	1	2	11.1	17.70	59.5
14	2	2	2	3	6.57	8.78	33.70	2	2	2	3	5.26	10.50	99.57
15	2	2	3	1	5.1	6.54	28.33	2	2	3	1	7.59	16.38	115.78
16	2	3	1	3	3.64	6.53	79.45	2	3	1	3	12.6	14.18	12.51
17	2	3	2	1	6.2	8.84	42.52	2	3	2	1	4.28	9.94	132.32
18	2	3	3	2	3.25	6.09	87.49	2	3	3	2	6.08	12.11	99.1

RESULTS

The S/N ratios were calculated using Eq. 1 to determine the parameters with the lowest surface roughness after weathering. Table 3 shows the distribution of the average S/N ratios calculated for the surface roughness according to the control factors. The largest S/N values show the most suitable process parameter for surface roughness. Main effect plots showing the change in the S/N ratios are given in Fig. 1. When the S/N ratios in Fig. 1 are examined, the lowest surface roughness after weathering occurred in radial direction, 0.5 W/m^2 UV, 4 h conditioning, and 45 min water for Scots pine wood, and in tangential direction, 0.5 W/m^2 UV, 2 h conditioning, and 15 min water for poplar wood.

Table 3. S/N Response Table for Scots Pine and Poplar (Smaller is Better)

Level	Scots Pine				Poplar			
	A	B	C	D	A	B	C	D
1	-29.15	-25.60	-31.15	-30.83	-32.81	-23.27	-30.77	-29.54
2	-30.96	-32.32	-23.42	-33.04	-32.10	-38.64	-32.49	-38.29
3	-	-32.25	-35.59	-26.29	-	-35.45	-34.10	-29.52
Delta	1.82	6.72	12.18	6.75	0.71	15.37	3.33	8.77
Rank	4	3	1	2	4	1	3	2

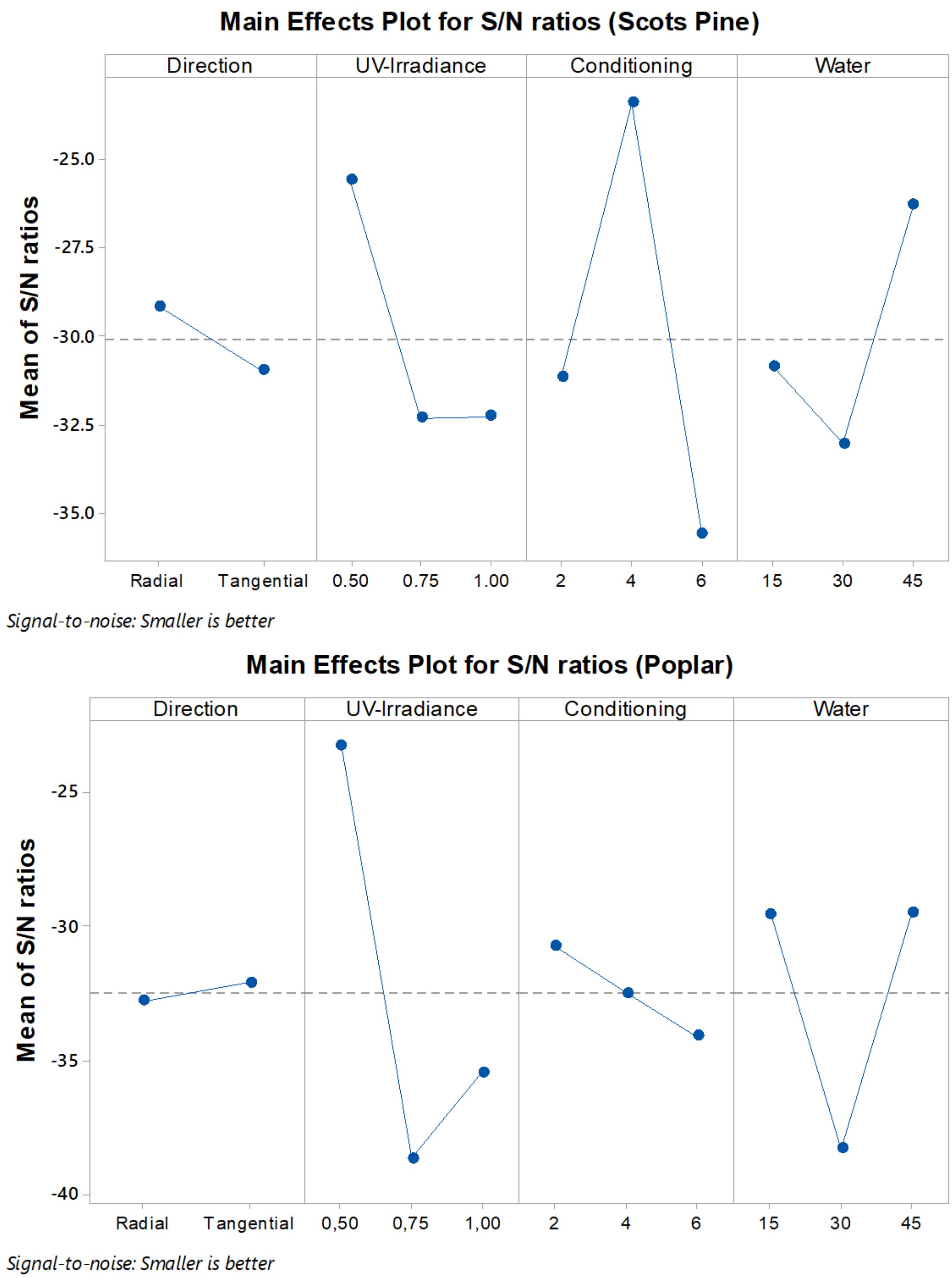

Fig. 1. Main effect plots for S/N ratios in Scots pine and poplar

Based on the analysis of variance (ANOVA) analysis when performed to determine the effect levels of the control factors on the surface roughness (Table 4), it was seen that conditioning had a maximum effect of 38% on the R_a value in Scots pine wood and wavelength with 31% in poplar wood. It can be said that tree orientation had no effect on

R_a values. However, high error margins were obtained in both tree species. It is stated that this value can be accepted when as high as 50%, and more high error values indicate that some important factors are definitely missed, conditions are not fully controlled, or the measurement error is excessive (Ross 1988; Idris *et al.* 2002; Pourjafar *et al.* 2013). The change in surface roughness with conditioning can be related to the applied temperature. In different studies it is stated that the surface roughness decreases with the effect of temperature (Ayrılmış and Winandy 2009; Kasemsiri *et al.* 2012; Yazıcı and Özlüsoylu 2020). However, only the effect of weathering conditions relative to the surface roughness was examined in the study, and different factors can also affect the surface roughness. The weathering causes some deteriorations of the sample surface depending on decrement in molecular weight of the polymer in concern with characterization for the surface roughness, and this leads an increase of roughness on composite surface. Using the water system helps in removing and washing solubilized degradation products from the wood surface. Water removes loosened fibers and particles produced during the UV irradiation. The wood surfaces exposed UV irradiation and water spray contain numerous checks, splits, and cracks (Çavdar *et al.* 2021). In a study, it was stated that the roughness values increased in parallel with the increase in the aging time (Yazıcı and Özlüsoylu 2020). Fidan *et al.* (2019) stated that the surface roughness of beech and spruce woods exposed to the effect of accelerated UV aging increased, and anatomical features may have an effect on color and roughness depending on the tree species. In addition, it has been emphasized in different studies that there are many factors affecting the surface roughness such as annual ring structure, young wood, mature wood, density, cell structure (Dundar *et al.* 2008; Istek *et al.* 2019).

Table 4. ANOVA Results for Scots Pine and Poplar Woods

Parameters	Code	DF	Sum of Squares (SS)	Mean Squares (MS)	F-Value	Contribut. Rate	Rank
	Scots pine						
Direction	A	1	0.2	0.17	0.00	0.00	4
UV-Irradiance	B	2	4424.4	2212.21	3.13	22.40	2
Conditioning	C	2	7552.8	3776.41	5.35	38.25	1
Water	D	2	707.8	353.90	0.50	3.58	3
Error	-	10	7063.1	706.31	-	35.77	-
Total	-	17	19748.3	-	-	100	-
	Poplar						
Direction	A	1	95.6	95.63	0.07	0.32	4
UV-Irradiance	B	2	9106.2	4553.11	3.38	30.72	1
Conditioning	C	2	1647.7	823.87	0.61	5.56	3
Water	D	2	5338.7	2669.36	1.98	18.01	2
Error	-	10	13453.5	1345.35	-	45.39	-
Total	-	17	29641.8	-	-	100	-

When the surface effect graphs of the two factors that had the most effect on Scots pine and poplar woods are examined, it can be seen that the change in R_a values in Scots pine wood at approximately 0.5 W/m^2 UV wavelength and 2 to 4.5 h of conditioning decreased below 20%. In poplar, the change in R_a values decreased below 20% with 0.5 W/m^2 UV wavelength and 15 min of water.

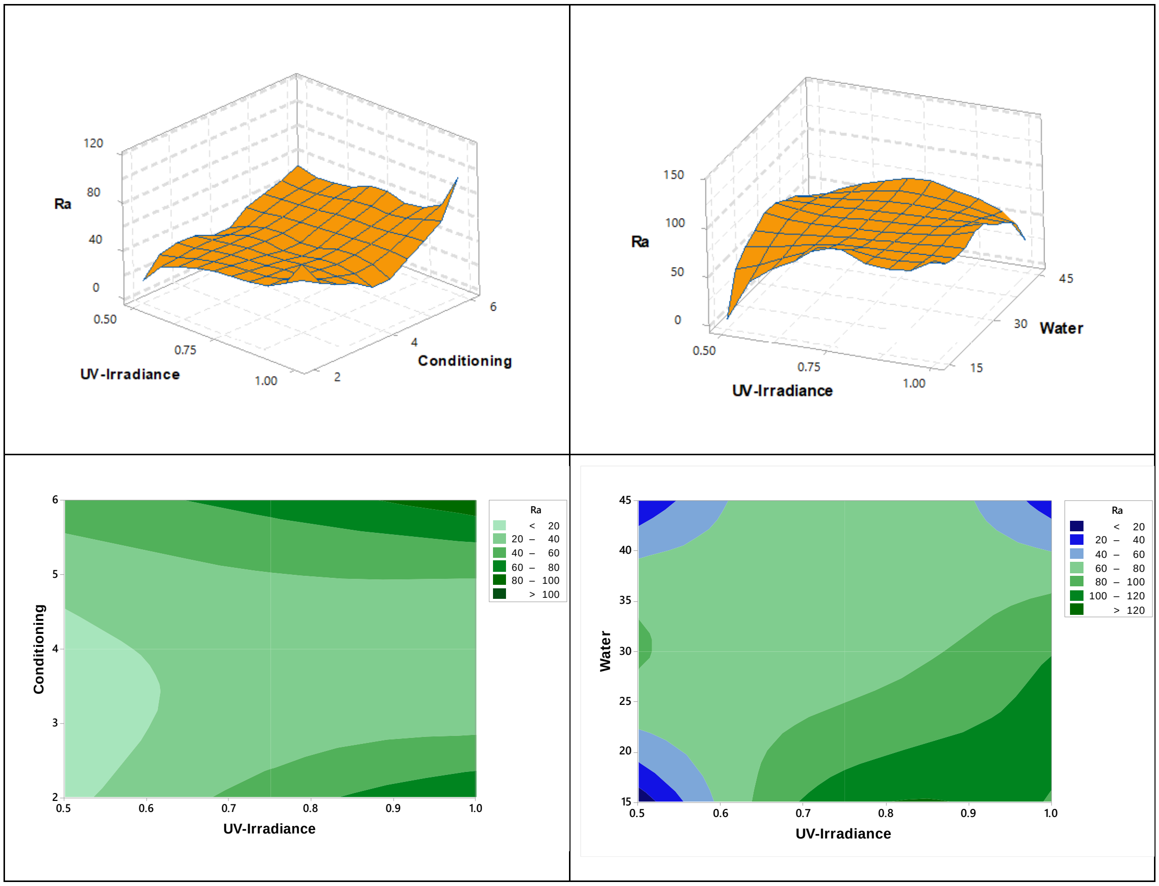

Fig. 2. Surface effect graphics

In future studies, the surface roughness can be optimized comparatively by using different optimization methods and different tree species.

CONCLUSIONS

1. The effects of accelerated weathering parameters on the surface roughness of Scots pine (*Pinus sylvestris* L.) and poplar (*Populus* x *euroamericana*) wood surfaces was examined in this study. The L_{18} Taguchi orthogonal array was used to optimize four parameters deemed to be useful on surface roughness. The ANOVA analysis was used to examine the experimental outcomes. The parameters with the lowest surface roughness after weathering were determined as radial direction, 0.5 W/m^2 UV, 4 h conditioning, and 45 min water for Scots pine, and tangential direction, 0.5 W/m^2 UV, 2 h conditioning, and 15 min water for poplar wood.

2. Conditioning had a maximum effect of 38% on the R_a value in Scots pine wood and wavelength with 31% in poplar wood. The change in R_a values decreased below 20% with 0.5 W/m^2 UV wavelength and 2 to 4.5 h of conditioning in Scots pine wood, 0.5 W/m^2 UV wavelength, and 15 min water in poplar wood.

REFERENCES CITED

Aras, O., and Sofuoğlu, S. D. (2021). "The relationship of machining parameters with surface roughness in machining of chestnut (*Castanea sativa* Mill.) tree species with CNC," *Furniture and Wooden Material Research Journal* 4(2), 114-125. DOI: 10.33725/mamad.992157

ASTM G154-16 (2016). "Standard practice for operating fluorescent ultraviolet (UV) lamp apparatus for exposure of nonmetallic materials," ASTM International, West Conshohocken, PA, USA.

Ayrılmış, N., and Winandy, J. E. (2009). "Effects of post heat-treatments on surface characteristics and adhesive bonding performance of medium density fiberboard," *Materials and Manufacturing Processes* 24(5), 594-599. DOI: 10.1080/10426910902748032.

Çabuk, Y., Karayılmazlar, S., Aytekin, A., Onat, S. M., and Kurt, R. (2014). "The Turkish paper and paperboard industry: A study of the statistical assessment, analysis and forecast," *Journal of the Faculty of Forestry Istanbul University* 64(1), 67-79. DOI: 10.17099/JFFIU.55245

Can, A. (2018). *Investigation of the Performance of Wood Preservatives Combined with Some Water Repellents*, Ph.D. Dissertation, Bartın University, Bartın, Turkey.

Çavdar, A. D., Tomak, E. D., Torun, S. B., and Arpaci, S. S. (2021). "Accelerated weathering resistance of high-density polyethylene composites reinforced with microcrystalline cellulose and fire retardants," *Journal of Building Engineering* 39, article no. 102282. DOI: 10.1016/j.jobe.2021.102282

De la Caba, K., Guerrero, P., Del Río, M., and Mondragon, I. (2007). "Weathering behaviour of wood-faced construction materials," *Construction and Building Materials* 21(6), 1288-1294. DOI: 10.1016/j.conbuildmat.2006.02.008

Dundar, T., As, N., Korkut, S., and Unsal, O. (2008). "The effect of boiling time on the surface roughness of rotary-cut veneers from oriental beech (*Fagus orientalis* L.)," *Journal of Materials Processing Technology* 199(1-3), 119-123. DOI: 10.1016/j.jmatprotec.2007.07.036

Feist, W. C., and Hon, N. D. (1984). "Chemistry of weathering and protection," in: *The Chemistry of Solid Wood*, American Chemical Society, Seattle, WA, USA, pp. 401–451.

Fidan, M. S., Ertaş, M., Kaya, S., and Karademir, A. (2019). "Effects on the surface roughness and color measurement of beech and spruce wood exposed to accelerated UV weathering," *İklim Değişikliği ve Çevre* 4(2), 1-9.

Idris, A., Ismail, A. F., Noordin, M. Y., and Shilton, S. J. (2002). "Optimization of cellulose acetate hollow fiber reverse osmosis membrane production using Taguchi method," *Journal of Membrane Science* 205(1–2), 223-237. DOI: 10.1016/S0376-7388(02)00116-3

Istek, A., Özlüsoylu, I., Can, A., and Onat, S. M. (2019). “The effect of vermiculite usage on surface properties of medium density fibreboard,” *Journal of Anatolian Environmental and Animal Sciences* 4(4), 607-612. DOI: 10.35229/jaes.636387

ISO 554 (2016). “Standard atmospheres for conditioning and/or testing-Specifications,” International Organization for Standardization, Geneva, Switzerland.

ISO 25178-2 (2012). Geometrical product specifications (GPS) — Surface texture: Areal — Part 2: Terms, definitions and surface texture parameters,” International Organization for Standardization, Geneva, Switzerland.

Kamperidou, V., and Barboutis, I. (2021). “Natural weathering performance of thermally treated poplar and black pine wood,” *Maderas. Ciencia y Tecnología* 23, 2-12. DOI: 10.4067/S0718-221X2021000100424

Kasemsiri, P., Hiziroğlu, S., and Rimduist, S. (2012). “Characterization of heat treated eastern redcedar (*Juniperus virginiana* L.),” *Journal of Materials Processing Technology* 212(6), 1324-1330. DOI: 10.1016/j.jmatprotec.2011.12.019

Kaygin, B., Koc, K. H., and Hiziroglu, S. (2014). “Surface quality and hardness of eastern redcedar as function of steaming,” *Journal of Wood Science* 60(4), 243-248. DOI: 10.1007/s10086-014-1399-x

Kivak, T. (2014). “Optimization of surface roughness and flank wear using the Taguchi method in milling of Hadfield steel with PVD and CVD coated inserts,” *Measurement* 50(1), 19-28. DOI: 10.1016/J.MEASUREMENT.2013.12.017

Kılıç, A., and Hafızoğlu, H. (2007). “Influences of weathering on chemical structure of wood and protection treatments,” *Turkish Journal of Forestry* 8(2), 175-183. DOI: 10.18182/TJF.51362

Koksoy, O., and Muluk, F. Z. (2004). “Solution to the Taguchi’s problem with correlated responses,” *Journal of Science* 17(1), 59-70.

Kurt, R., and Can, A. (2021). “Optimization of the effect of accelerated weathering conditions on wood surfaces *via* the Taguchi method,” *BioResources* 16(1), 1642-1653. DOI: 10.15376/BIORES.16.1.1642-1653

Kurt, R., and Imren, E. (2021). “Regional clusters, similarities, and changes in turkey's wood production: A comparative analysis using K-means and Ward's clustering methods,” *Wood Industry/Drvna Industrija* 72(4), 337-346. DOI: 10.5552/drvind.2021.2031

Masmiati, N., and Sarhan, A. A. D. (2015). “Optimizing cutting parameters in inclined end milling for minimum surface residual stress – Taguchi approach,” *Measurement* 60, 267-275. DOI: 10.1016/J.MEASUREMENT.2014.10.002

Pourjafar, S., Jahanshahi, M., and Rahimpour, A. (2013). “Optimization of TiO_2 modified poly(vinyl alcohol) thin film composite nanofiltration membranes using Taguchi method,” *Desalination* 315, 107-114. DOI: 10.1016/J.DESAL.2012.08.029

Ross, P. J. (1989). *Taguchi Techniques for Quality Engineering, Loss Function, Orthogonal Experiments, Parameter and Tolerance Design*, McGraw Hill, New York, NY, USA.

Ross, P. J. (1988). *Taguchi Techniques for Quality Engineering*, McGraw Hill, New York, NY, USA.

Taguchi, G., Elsayed, E. A., and Hsiang, T. C. (1989). *Quality Engineering in Production Systems*, McGraw-Hill Companies, New York, NY, USA.

Temiz, A., Yildiz, U. C., Aydin, I., Eikenes, M., Alfredsen, G., and Çolakoglu, G. (2005). “Surface roughness and color characteristics of wood treated with preservatives after accelerated weathering test," *Applied Surface Science* 250(1–4), 35-42. DOI: 10.1016/J.APSUSC.2004.12.019

Williams, R. S. (2005). "Weathering of wood," in: *Handbook of Wood Chemistry and Wood Composites*, R. M. Rowell (ed.), Madison, FL, USA, pp. 139-185.

Yang, W. H., and Tarng, Y. S. (1998). "Design optimization of cutting parameters for turning operations based on the Taguchi method," *Journal of Materials Processing Technology* 84(1–3), 122-129. DOI: 10.1016/S0924-0136(98)00079-X

Yazıcı, H., and Özlüsoylu, İ. (2020). "The effect of accelerated weathering on some surface properties of heat-treated sweet bay wood (*Laurus nobilis* L.)". *Turkish Journal of Forestry* 21(4), 468-474. DOI: 10.18182/tjf.809139

Zhang, J., Kamdem, D. P., and Temiz, A. (2009). "Weathering of copper–amine treated wood.-," *Applied Surface Science* 256(3), 842-846. DOI: 10.1016/j.apsusc.2009.08.071

Article submitted: June 22, 2022; Peer review completed: September 11, 2022; Revised version received and accepted: September 21, 2022; Published: October 14, 2022.
DOI: 10.15376/biores.17.4.6668-6678